Calculation Technique and Structure of the GNSS-stations Velocity Database

Data

The region covered by our velocity database (VDB) approximately coincides with East European Craton (EEC). The permanent GNSS-stations of IGS (http://www.igs.org/network) and EPN (http://epncb.oma.be/) nets as well as GNSS-stations of national geodetic nets of

Estonia (http://www.maaamet.ee/),
Latvia (http://latpos.lgia.gov.lv/) and
Finland (http://euref-fin.fgi.fi/fgi/en/positioning-service/rinex-service)

are included in VDB. All stations of the Finnish geodetic network are now posted on the EPN website. The Latvian Geodetic Survey data are unavailable in free since 2019(231), Estonian – since2024(108).

GNSS-stations of Russia are presented by geodetic companies

PRIN (http://www.prin.ru/seti_referencnyh_stancij/),
Hexagon (http://smartnet. geosystems.ru/),
RGS-Centre (http://new.rgs-centre.ru/) and
GSI (GeoStroyIziskaniya, http://topnet.gsi.ru),
RSS (http://russianspacesystems.ru/bussines/navigation/sdkm/),
EFT (https://eft-cors.ru/).

The more dense net of Saint-Petersburg and its suburbs is presented by geodetic companies GEOMATIC (http://www.geospider.ru/) and corresponding department of the Municipal Engineering and Architecture committee of SPb (http://ref.kgainfo.spb.ru/). We also used the data of GNSS-stations of some European and Russian universities and other state institutions with free data access.

We appreciate all our colleagues for the opportunity to use the GNSS-observations for our research studies.

Processing of initial data

The initial GNSS-observations (daily, 30 sec, RINEX) are permanently processing by Gipsy 6.4 (JPL NASA) software by means of PPP strategy (Precise Point Positioning). The next options have been taken into account:

– absolute antennas calibration,
– final satellite orbits (centered to the total Earth's mass) and clock corrections according to IGS14 (IERS2010 standard) (ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products/Final),
– IERS Earth orientation parameters (EOP C04) (http://hpiers.obspm.fr/eop-pc/),

– troposphere model isVMF1/ECMWF
(http://ggosatm.hg.tuwien.ac.at/DELAY/GRID/STD/),
– all solid Earth tidal variation including pole tide,
– ocean tide loading is GOT 4.8(http://holt.oso.chalmers.se/loading/), corrected for center of Earth mass moving,
– second order ionospheric influence by IONEX model
(http://cddis.gsfc.nasa.gov/gps/products/ionex).

The mass loading corrections (atmospheric and nontidal oceanic loading) are also considering from IMLS (http://massloading.net/).

Processing of position series

The next regression model is using for position processing:

$$x_i = X_0 + Vt_i + a_1 \sin(2\pi t_i) + a_2 \cos(2\pi t_i) + a_3 \sin(4\pi t_i) + a_4 \cos(4\pi t_i) + v_i \quad (1)$$

Here are x_i – current value of any coordinate (north, east and up, in mm) for observation time t_i (in years), X_0 – first day station position, $a_{1\text{-}4}$ – seasonal coefficients of station positions, v_i – noise component, V – required station velocity (in mm/year) for corresponding coordinate. The WLSS (the weights are defined from daily position variance) is used for solution of (1) as well as robust one (median - $\min\{\sum | x_i - (X_0 + Vt_i) |\}$) for truncated model without seasonal terms a_1 - a_4.

The outliers are excluded as by TEQC qualitative estimations of narrow lanes (< 25%) and time span (< 4 hours) as by consistently used statistic algorithm (3σ), where in place of σ we use Allan deviations, which is more efficient for series with systematic errors:

$$\sigma_A = \sqrt{\Sigma(x_i - x_{i+1})^2 / (2(N-1)} \quad (2)$$

The stepwise discontinuities (jumps) in any coordinate were assessed by the same algorithm as for the time of equipment changes (receiver or antenna) at the station as for any stochastic moments between $t_i + dt$ and $t_i - dt$. The value of jump $\Delta = X_I - X_{II}$ is estimated for time span (dt < 20 days) before and after assumed jump moment. The significance of stepwise jump is estimated by Fisher's test $F = \sigma^2 / \sigma_b^2$, where b corresponds to the variance with the jump included, $\sigma^2 = \Sigma v_i v_i / (N - Nu)$, N_u – is the number of parameters (N_u = 6 for (1)). If F > 1.2 then the stepwise discontinuities is recognized as significant with p = 0.999 for length of the series more than 3 years (N>1000).

Some position series were merged when successively replaced each other in the same place (up to some meters sometimes) equipment was used. The corresponding jumps were estimated and applied in this case.

The GNSS position series, after the removal of trends and quasi-periodic components, are the stochastic noise with a power spectrum that is well approximated by a power-law dependence on the frequency *f*:

$$P(f) \propto f^{-\beta}.$$

For stochastic signals with such power spectrum for integer values of *β*, the following simple calculations of the station velocities are given in [1]. For normally distributed noise ($\beta = 0$), station velocity errors

$$\sigma_n \cong \frac{a}{T}\sqrt{12/n}, \qquad (3)$$

almost coincide with formal LSM errors. Here *a* is the average value of the noise amplitude, for which we used the estimate σ_A from (2), $T = \Delta T\ (n - 1)$ - the duration of observation series with a constant increment ΔT (in years)

Two estimation methods of *β* [2,3] are used for series from VDB. The range of *β* is $0.6 < \beta < 1$. Thus, on the average, the type of noise distribution is closer to the flicker noise ($\beta = 1$) for our VDB. In this case, the errors depend only on the length of the series and the mean amplitude of noise σ_A:

$$\sigma_f \cong 0.75\frac{\sigma_A}{T} \qquad (4).$$

Depending on the weighted average of both estimates *β,* the corresponding station speed error was calculated using formulas (3) or (4).

For median velocity estimation, we used instead of σ_A in (4) the mean absolute deviation $\sigma_P = \Sigma|v_i|/N$.

File formats of VDB

The any of solutions are presented by the files with corresponding labels (LSS and MED) - ***LISTA, LIStat***. The files LISTA hold a main information. The files LIStat contain statistical data of all series. The ***LISTseason*** and ***LISTjump*** files contain information about season components and jumps (discontinuities) in series. The ***equipment*** (gao_with_former.snx**)** file is similar IGS file (igs_with_former,snx) and contains information about equipment changes in GNSS stations. The ***LISTclosed*** file contains a list of stations that either completed observations or are no longer supported by us in processing.

These files contain data from stations with more than two years observations.

Format of LISTA:

1. Name & Co– name of station and country of it location.
2. Lat – rough latitude of station (in degree).
3. Long – rough longitude (in degree).

4. Up(m) – height (in meter).
5. VnPM – north velocity of station in ITRF2014 (in mm/year).
6. VePM – east velocity of station in ITRF2014 (in mm/year).
7. Vh – vertical velocity in mm/year.
8. Vn – north component of velocity (mm/year) transformed by the ITRF2014 absolute rotation pole for Eurasia [2], positive to the north.
9. Ve – the same for east component, positive to the east

10 – 12. sVn, sVe, sVu – corresponding LSS-errors, equal for LSS and MED.

13 – 15. sVnf, sVef, sVuf – corresponding flicker-noise errors.

16. dT(y) – length of the series (in years).
17. Yfin – last epoch in series.
18. N – amount of days in series.
19. Jumps – breaks in series for equipment changing and for statistics.

Format of LIStat

1. Name – name of station.
2. YearS – start epoch of series.
3. YearF – final epoch of series.
4. %use = N/(YearF –YearS)/365.25 – observational efficiency.
5. N>30 – the number of missed observations with time span more than 30 days.
6. Ncr – the number of outliers because of TEQC restrictions.
7. Nsi – the number of outliers because of large position errors inside a day.
8. Nout – the number of statistical outliers in series
9. N – days of observation.
10. ADEV – Allan deviation, (2).
11. Sig1 – LSS errors or mean absolute deviation for MED solution.

12 – 13. sV,sVf – velocity errors from (3) and (4).

14 -15. estimation of β by the two methods above (μ and H).

16. NEU – coordinate pointer.

The interactive map of GNSS stations

The map of GNSS station from the VDB contains two types of figures for each station. The first one (*Station-EA Plate motion (ITRF14) - shifts*) contains position series (dN, dE, dUp, in mm) after removing of the Eurasian plate motion rotation according [4] and stepwise discontinuities (jumps) if they were. (Corresponding series can be provided on request). The estimated ITRF14 velocities and Allan deviations (2) are given for each component. The residuals of station positions after removing of the seasonal models (1) (green line) and outliers are presented in the second figure. The residuals of station velocities and its errors for both type of noise distribution (white and flicker) is also given here.

The drop-shaped sing is used when some stations have very close positions or successively replaced each other in the same place. It was possible to combine some of these position series in one set (see file LISTjump). The sing with “P” marks stations finished observation or station no longer serviced by us.

The map shows all stations, including stations with observations of less than two years.

The website https://vesta.pu.ru/vdb contains a new version of the map with expanded features, for example the provision of numerical variations of the station positions.

When using this database, please refer to the article:

Gorshkov V.L., Mokhnatkin A.V., Shcherbakova N.V., (2021) GNSS-stations velocity database on the East European Craton for research and practical applications. Geodesy and cartography = Geodezia i Kartografia, 967(1), pp. 34-44. (In Russian). DOI: 10.22389/0016-7126-2021-967-1-34-44

LITERATURE:

1. *Williams S.D.P. (2003)* The effect of coloured noise on the uncertainties of rates estimated from geodetic time series // J. Geodesy (2003) 76, 483-494.
2. *Allan, D.W. and J. A. Barnes* (1981). A Modified “Allan Variance” with Increased Oscillator Characterization Ability, Proceedings of the 35th Annual Frequency Control Symposium, P. 470–475.
3. *Flandrin P,* (1989). On the spectrum of Fractional Brownian motion, IEEE trans. on inform. theory, Vol. 35, No. 1, 197-199.
4. *Altamimi, Z., L. Metivier, X. Collilieux*. ITRF2014 plate motion model // Geophys. J. Int. (2017) 209, 1906–1912, doi: 10.1093/gji/ggx136.

Comparison velocities of the VDB and global database NGL

Our study of the velocity consistency of GNSS stations from our VDB and the global database of the Geodetic laboratory of the Nevada University (NGL, http://geodesy.unr.edu) over the territory of the East European Craton showed a remarkable agreement between the velocities given in the table below.

Comparison of velocities (VDB - NGL) for 171 common GNSS stations

<table>
<tr><th>DB</th><th>ΔVe(mm/y)</th><th>ΔVn(mm/y)</th><th>ΔVu(mm/y)</th><th>sVe</th><th>sVn</th><th>sVu</th><th>% use</th></tr>
<tr><td>VDB</td><td rowspan="2">-0.02 ± .24</td><td rowspan="2">0.03 ± .23</td><td rowspan="2">0.04 ± .65</td><td>0.13</td><td>0.12</td><td>0.31</td><td>90.46</td></tr>
<tr><td>NGL</td><td>0.18</td><td>0.17</td><td>0.73</td><td>91.73</td></tr>
</table>

This similarity of velocity estimates, as well as the homogeneity of the data processing methods used in both databases (GIPSY), makes it possible to include extensive material from the NGL database in the western territory of the EEC in a joint geodynamic analysis. In total, there are about a thousand stations from the NGL on this territory, including 171 common ones from the VDB.

It is also visible from the table, that the average error in the vertical velocities of the NGL base (sVu) significantly exceeds the error of the VDB. This is probably due to the shortcoming of the filtering method (MIDAS) used in the NGL to search for step discontinuities, which is more pronounced precisely on the vertical component, especially when changing equipment at stations. A slightly lower of the VDB errors for the horizontal velocities can be due to the inclusion of load corrections in our VDB (atmospheric and non-tidal).